

Progress on VLBI Ecliptic Plane Survey

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Abstract We launched the VLBI Ecliptic Plane Survey program in 2015. The goal of this program is to find all compact sources within 7.5 degrees of the ecliptic plane which are suitable as phase calibrators for anticipated phase referencing observations of spacecrafts. We planned to observe a complete sample of the sources brighter than 50 mJy at 5 GHz listed in the PMN and GB6 catalogues that have not yet been observed with VLBI. By April 2016, eight 24-hour sessions have been performed and processed. Among 2227 observed sources, 435 sources were detected in three or more observations. We have also run three 8-hour segments with VLBA for improving positions of 71 ecliptic sources.

Keywords radio astrometry, catalogues, ecliptic plane, high sensitivity observations

1 Introduction

This paper presents the status report of the ongoing VLBI Ecliptic Plane Survey (VEPS) program. The first goal of the program is to search for more ecliptic calibrators with a minimum network of 3 stations. We consider a source that is brighter than 30 mJy at baseline projection length 5000 km as a calibrator. We have se-

lected all objects within 7.5° of the ecliptic plane, with single dish flux densities brighter than 50 mJy at 5 GHz from the PMN (Parkes-MIT-NRAO) and GB6 (Green Bank 6 cm) catalogues except for those:

- that have been detected with VLBI before
- that were observed with VLBI in a high sensitivity mode (detection limit better than 20mJy), but have not been detected.

As the target sources number is more than 7000, we planned to observe in two phases.

- Phase-A — Observations of 2216 sources that have total flux density at 5 GHz > 100 mJy
- Phase-B — Observations of 4802 sources that have total flux density at 5 GHz in the range [50, 100] mJy

More details about observations of this large sample of target sources will be described in section 2-4.

The second goal of the VEPS program is to improve the position accuracy better than 1.5 nrad for those ecliptic calibrators detected in various VLBI experiments, but with large position uncertainties. This type of observations should be performed at S/X dual band and use a large network such as VLBA, EVN or IVS in a high sensitivity mode. We will address this issue in section 5.

2 Observations

The phase-A observations began in February 2015. The participating stations include the 3 core Chinese VLBI stations: Seshan25, Kunming and Urumqi. However, sometimes they cannot be available at the same time,

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or occasionally one or two of them have a risk of failure. In that case, one or two international stations are required.

Fig.1 shows the geographical distribution of all participating stations. Kashima34, Sejong and Hobart26 have contributed to the past VEPS observations. They have middle-sized antennas, and good common visibility for the ecliptic zone. Before joining in the VEPS survey, we made fringe tests to Sejong, Hobart26 and Kashima34 in December 2014, July 2015, and January 2016 respectively.

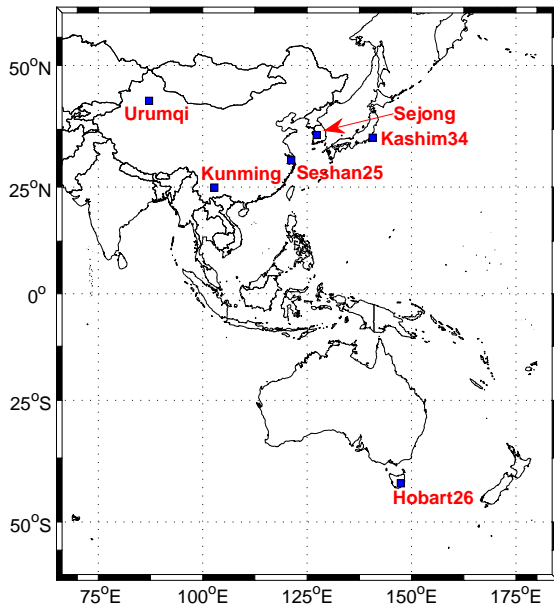


Fig. 1 Distribution of participating stations.

So far 8 sessions have been observed, as summarized in Table 1. Each target source was observed in two scans of 90 seconds. 4 calibrators were observed every 1 hour for reduction of atmospheric effects and amplitude calibration.

Fig.2 shows the frequency sequence used in the phase-A observations. 8 USB channels and 8 LSB channels spread over about 800 MHz frequency range at X-band result in 16 IF channels, and the bandwidth for each IF channel is 32 MHz, so the total data rate is 2048 Mbps with 2 bit sampling. The data volume is close to 16 TB for each station in one 24 h session.

For Sejong station, the maximum rate is 1024 Mbps, so the data sampling was changed to 1 bit. For Hobart26, its 32 MHz bandwidth had not been

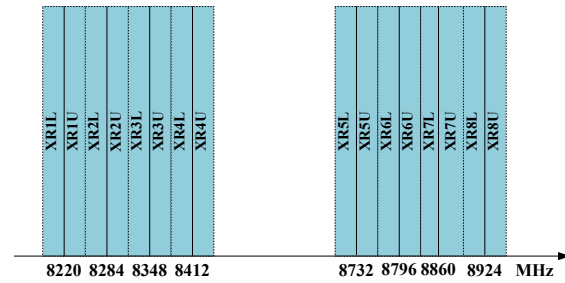


Fig. 2 Frequency sequence used in the VEPS observations

tested at that time, so we observed the first 16 MHz bandwidth for each IF channel instead. In the case of 1024 Mbps data rate, the data volume is close to 8 TB for each station in one session.

3 Data processing

The data from the Chinese domestic stations were recorded on 16-TB diskpicks and then shipped to Shanghai, while the data from international stations were transferred to Shanghai via high speed network. The data volume for each session is much bigger than that of regular geodetic sessions, so the data processing is very time-consuming. Another technical issue is the correlation of mixed observing modes with different bandwidths or sampling bits. This could be supported by the DiFX correlator installed at Shanghai, which also serves as one of the IVS correlators.

For the correlation of 1-bit sampled data from Sejong against 2-bit sampled data from the other stations, a different treatment was implemented in the station based processing module, and it turned to be the same after the data being transformed to the frequency domain.

For the correlation of 16 MHz bandwidth data from Hobart26 against 32 MHz bandwidth from the other stations, the zoom mode was selected to pick up the overlapped frequency band. Moreover, it was optional to make correlation only on the 16 MHz bandwidth on the baselines to Hobart26, while the other stations with 32 MHz bandwidth went through an independent correlation pass, the same as the usual correlation procedures.

Table 1 Summary of the VEPS observations

Date (yyyy-mm-dd)	Time UT	Dur hrs	Code	Stations	Frequency	Data rate (Mbps)	Channels	Sampling (bits)	Data volume (TB)	# Targets
2015-02-13	05h00m	24	VEPS01	ShKmUr	X	2048	16	2	48	293
2015-02-14	06h00m	24	VEPS02	ShKmUr	X	2048	16	2	48	338
2015-04-23	05h00m	24	VEPS03	ShKmUrKv	X	2048	16	2	56	300
2015-04-24	06h00m	24	VEPS04	ShKmUrKv	X	2048	16	2	56	400
2015-08-10	05h00m	25	VEPS05	ShKmKvHo	X	2048	16	2	42	252
2015-08-19	05h00m	25	VEPS06	ShKmKvHo	X	2048	16	2	42	277
2016-03-02	08h30m	24	VEPS07	ShKmUrKb	X	2048	16	2	52	333
2016-03-11	05h00m	24	VEPS08	ShKmUrKb	X	2048	16	2	60	477

Note 1. — Sh: Seshan25; Km: Kunming; Ur: Urumqi; Kv: Sejong; Kb: Kashim34; Ho: Hobart26.

Note 2. — The mode 1024 (data rate) - 16 (channels) - 1 (bit) was used at Sejong.

Note 3. — The mode 1024 (data rate) - 16 (channels) - 2 (bit) was used at Hobart26.

4 Preliminary results

In general, the VEPS observing sessions were successful, though Urumqi had no fringes in the first half of VEPS01 session due to a receiver problem, and Seshan25 and Kunming had no fringes in VEPS03 due to incorrect use of B1950 source positions.

We have processed all of the observed sessions. Based on data analysis, there are 435 target sources that were detected in three or more observations among 2227 observed. The detection rate is about 20%. Their median position precision is about 18 nrad. The estimation of the correlated flux densities is better than 15%.

Except for the baselines to Sejong, the other baselines have detection limits better than 30 mJy. Deduced from the 4 VEPS sessions, the SEFD of Sejong varied from 3000 to 5000, which can also be confirmed by the IVS sessions it participated in. The causes are under investigation and may be related to the antenna pointing model, aperture efficiency as a function of frequency or the receiver system.

Fig.3 and Fig.4 shows the distribution of Phase-A sources and Phase-B sources respectively. Most Phase-A sources have now been observed. We can see there are two holes in the plots beside 200 degrees of ecliptic longitude. In the PMN surveys, these small regions were severely affected by solar contamination when the sidelobes of the antenna were encountering the Sun, so those data have been expunged from the survey [1]. In the next VEPS sessions, we will try to fill the two holes with sources from other radio catalogues.

In order to finish the survey of remaining sources, an additional 400-hours of observing time will be required. We expect that Sejong will have a better per-

formance with improved SEFD and Hobart26 will use the DBBC2 2 Gbps mode.

5 High sensitivity astrometry

As of April 2016, we have observed 73 ecliptic sources with VLBA in three 8-hour segments at 2.3 and 8.6 GHz at 2Gbps (project code: BS250). The targets are the weakest calibrators with correlated flux density at baseline project lengths 5000 km in a range [30, 50] mJy. A priori positions of one half the targets were derived from single-band VLBI observations at 4 or 8 GHz. We scheduled each targets in three scans of 180s long. Two targets have not been detected at S-band. Position uncertainties of 71 remaining targets before our VLBA observations were in a range of [0.8, 294] nrad with median 6.2 nrad. After our VLBA observations, the position uncertainties dropped to the range of [0.7, 5.6] nrad, with median 1.8 nrad (See Fig.5).

Statistics of VLBI detected sources within $\pm 7.5^\circ$ of the ecliptic plane are shown in Table 2. The number of known calibrators in the ecliptic plane is growing rapidly and reached 1167 recently. Positions of only 23% have been determined with accuracy better than 1.5 nrad using S/X dual-band VLBI. Changes on 2016-04-01 with respect to 2016-02-01 are contributed by some VEPS, VCS9, and VCS-II experiments [2]. Changes on 2016-05-01 with respect to 2016-04-01 are contributed by the project BS250.

In order to improve positions of known calibrators, we plan to observe them with VLBA, EVN, or IVS. In a more practical sense, it might be a good idea to

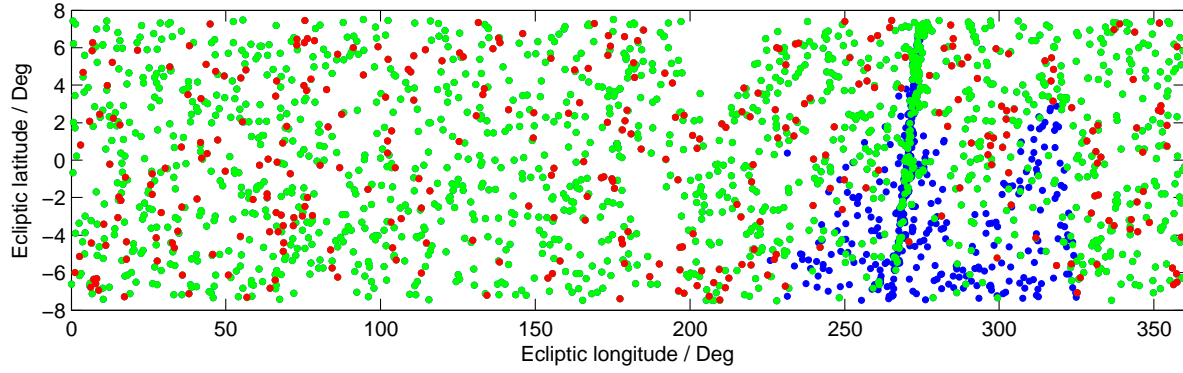


Fig. 3 Distribution of Phase-A sources. Among 2216 target sources (blue), 1903 sources (green) have been observed, 363 sources (red) were detected in 3 or more observations.

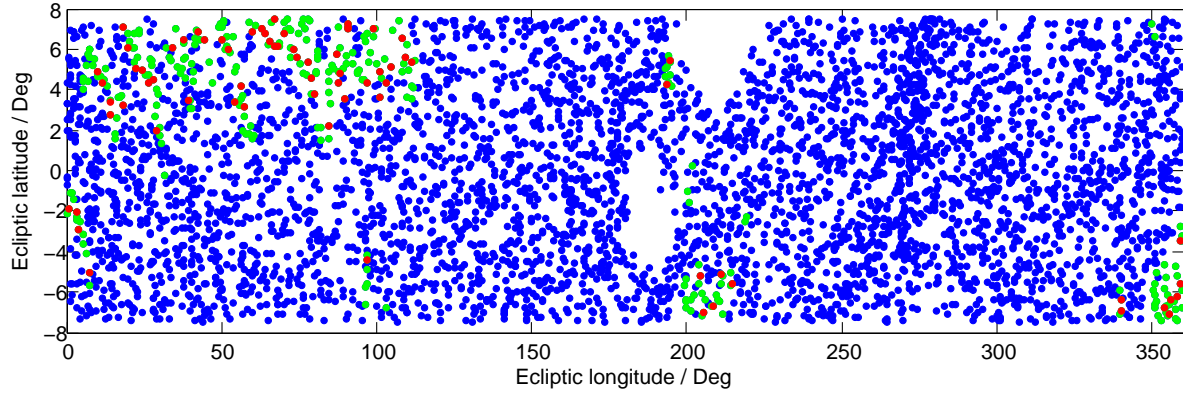


Fig. 4 Distribution of Phase-B sources. Among 4802 target sources (blue), 324 sources (green) have been observed, 72 sources (red) were detected in 3 or more observations.

Table 2 Statistics of sources detected with VLBI within $\pm 7.5^\circ$ of the ecliptic plane.

	2015-01-01	2016-02-01	2016-04-01	2016-05-01
# Calibrators with errors < 1.0 nrad	130	133	143	155
# Calibrators with errors < 1.5 nrad	187	191	261	293
# Calibrators with errors < 2.0 nrad	279	283	405	449
# Calibrators with errors < 2.5 nrad	336	349	479	533
# Calibrators with errors < 3.0 nrad	402	423	518	574
# Calibrators with errors < 5.0 nrad	521	549	625	681
Total # calibrators	772	969	1167	1167
Total # sources including non-calibrators	1154	1450	1710	1732

form a high sensitivity network with Asian and Oceanian antennas. In such a network, a compatible observing mode using S/X band at 2 Gbps needs to be defined and tested. With inclusion of the Tianma or Parkes radio telescopes, even the baselines to small antennas of AuScope will have sensitivity comparable with VLBA.

6 Conclusions

The VEPS observations for detecting more ecliptic calibrators are running smoothly and have become routine work now. More than 400 sources have been detected on VLBI baselines for the first time.

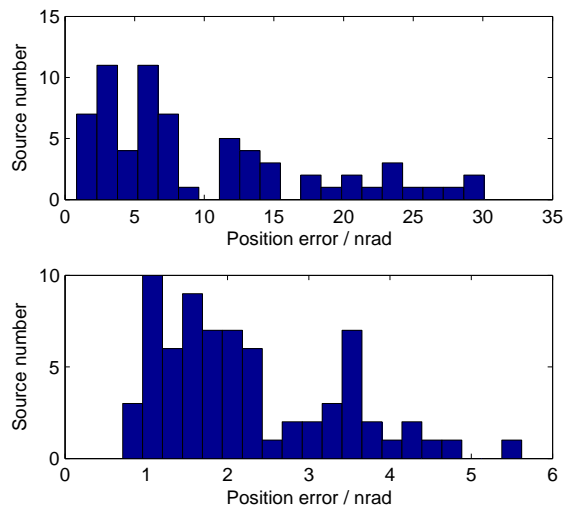


Fig. 5 Top: Histogram of position errors of 71 sources before the VLBA observations. Please note 4 sources with position error larger than 35 nrad are not included in the statistics. Bottom: Histogram of position errors of 71 sources after the VLBA observations.

The VEPS observations for improving positions of known calibrators will benefit from a proposed high sensitive network with Asian and Oceanian antennas.

Acknowledgements

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